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A MANNED-MACHINE SPACE STATION CONSTRUCTION CONCEPT

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INTRODUCTION

The NASA Space Station Task Force Concept Design Group has been developing the architecture and associated construction scenarios for a manned space station. This group has estimated that the eventual power demands of the station will require solar arrays with an area of about 3700 m^2 (40,000 ft^2) (150 kw continuous power). The initial design concept examined by the Design Group is shown in figure 1 and is based on the use of a long deployable beam similar to that of the reference 1 array. The shortcomings of this initial design are, (1) the full 150 kw array must be deployed at one time, (2) there is no potential for change or growth, and (3) a preliminary structural analysis has indicated that the fundamental natural frequency of the array would be approximately .004 hz. It is anticipated that such large low frequency structures would require an elaborate on-orbit control system.

As a result of these shortcomings, the Concept Design Group requested that the Structural Concepts Branch at LaRC explore structural configurations for very large solar arrays (150 kw continuous power) that were stiff enough that an elaborate on-orbit control system would not be required. The stiffness goal chosen was to develop a design with its lowest natural frequency greater than 0.4 hz. The other main considerations were that the solar array support structure be compatible with existing technology for deployable solar array blankets (ref. 1), and that the power array be capable of growing in a systematic modular

fashion from an initial space station that might require only 30 to 50 kw to one with the full 150 kw continuous power capability.

A design concept that satisfies these considerations is shown in figure 2 and reported upon in ref. 2. In this design, deployable solar array modules are attached perpendicular to a large central solar array support beam. For the design shown in figure 2, the array aspect ratio was reduced while maintaining the same area in an effort to move mass inboard, thus, improving its frequency characteristics. For the configuration shown, a three longeron triangular beam with a bay size of 16 feet 8 inches was required to achieve the frequency goal of .4 hz. For this concept, it was assumed that the solar arrays would be supported from two sides of the beam and thermal radiators would be supported by the third side.

For a beam of this size, it was apparent that the structure would have to be erected on-orbit. The overall construction scenario chosen was that the central support beam would be erected from the gimbal, bay-by-bay, and power modules put in place as growth required. Erectable techniques similar to that reported in ref. 3 were considered. In general, the construction was conceived to be accomplished by astronauts on EVA assisted by a machine that would be capable of moving from point to point on the beam as required. For the triangular array support beam shown in figure 2, it was visualized that the machine would move through the center of the beam much like an elevator, permitting the astronauts to move along the beam at will.

Further studies indicated that changing the solar array support beam from a triangular cross-section to a square cross-section could result in several significant benefits as follows:

1. For the same size members, a square beam has twice the moment of inertia as a triangular beam, thus, a smaller diameter cross-section could be used to achieve the design goal of 0.4 hz.
2. A square beam with one more side would permit the astronaut assisting machine to travel outside the beam on one side while leaving two sides for supporting the power arrays and the fourth for supporting thermal radiators.
3. The square beam configuration could also be used to construct a large platform if this were found to be desirable for the central core of the space station itself. Such a platform would permit the same machine used for beam construction to also be used for platform assembly due to the identical nodal spacing.

The following report is a description of a machine capable of assisting in erecting such a square beam and of several space station configurations that could be erected using this machine. A conceptual scenario showing how this machine could be used to construct other structures is also included. Finally, summary remarks are presented which highlight how the approach outlined in this paper could affect construction of a space station as well as its operations.

Other relevant references concerning the analysis, design and construction of large truss structures for space application are given in references 4 through 13.

INITIAL 150 kw SPACE STATION CONFIGURATION

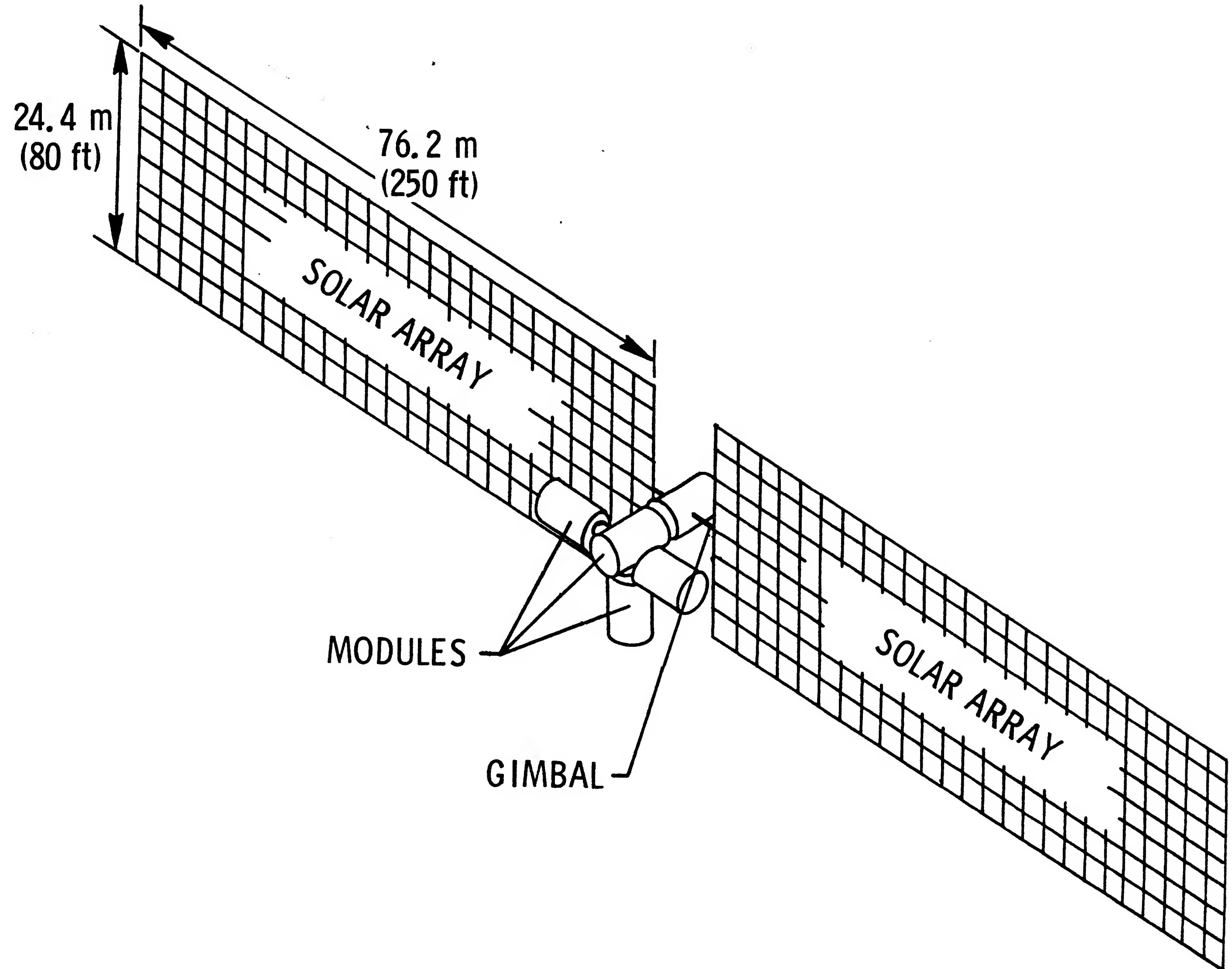


FIGURE 1

MODULE CLUSTER - GIMBALED WING ARRAYS

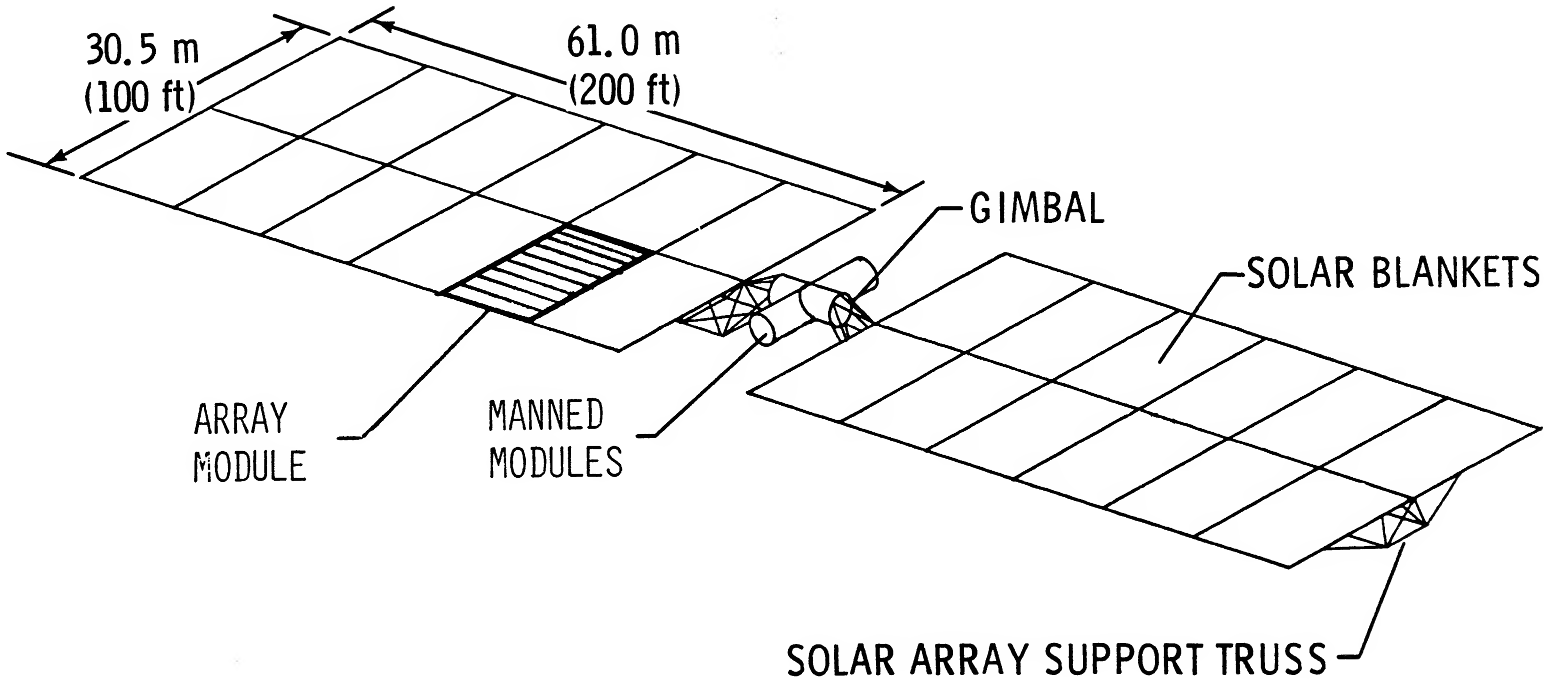


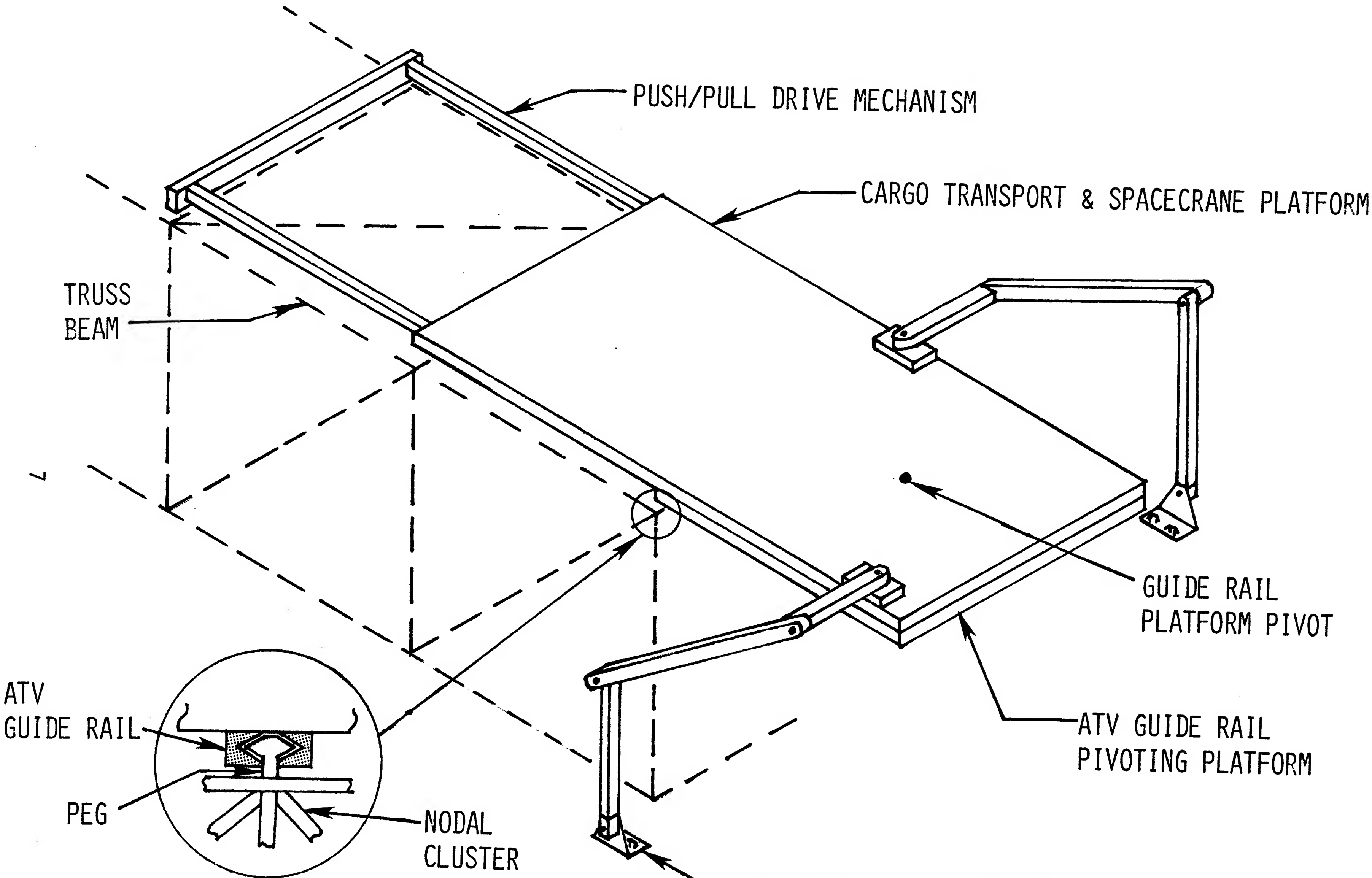
FIGURE 2

FIGURE 3

ASSEMBLY AND TRANSPORT VEHICLE

As discussed in the introduction, a square cross-section beam was chosen for construction of the solar-array support structure. An Assembly and Transport Vehicle (ATV) for constructing this beam (as well as platforms and other structures) is shown in figure 3. The ATV is a movable platform, powered by a push-pull drive mechanism which operates in "inch-worm" fashion to drive the platform one bay (strut length) at a time, using only gripping protrusions (pegs) located on top of each nodal cluster joint in a manner similar to that described in reference 4 and shown in the figure. The ATV spans two bays of the square beam. When the drive mechanism is extended, the ATV platform is moved "forward" one bay length, remaining firmly attached at four (4) nodal points (see Figure 3 inset for ATV and Truss Connection). Pressure suited astronauts, attached to foot-restraints, are positioned within their work envelope by movable manipulator arms in a manner similar to references 3 and 5. Erectable tubular struts are snapped into place beneath the overhanging ATV using the guide rails as an assembly fixture. The ATV will operate in either direction and may have a "space crane" attached for positioning payloads while the workstation astronauts attach the equipment to the structure. A third astronaut may "drive" the ATV, operate the space crane, and/or manually extract struts from a cannister and pass material to the two workstation astronauts.

ASSEMBLY AND TRANSPORT VEHICLE



ATV & TRUSS STRUCTURE CONNECTION

FIGURE 3

FIGURE 4

ASSEMBLY AND TRANSPORT VEHICLE DRIVE CONCEPT

One technique identified for driving the ATV is illustrated in figure 4, which shows a bottom and side view of a conceptual drive and guidance system. The operative components are shown in the figure and include (1) the push/pull drive mechanism, (2) nodal peg grabbers, (3) longitudinal and transverse guide rails, (4) longitudinal and transverse guide rail switches, and (5) a pivoted guide rail platform. It is considered that the ATV is an assemblage of conventional, state-of-the-art components such as redundant electric motors, rack and pinion drive and solenoid actuated two position mechanisms. The ATV is conceptually simple and could be low risk provided the implementation of the concept retains such simplicity.

ASSEMBLY AND TRANSPORT VEHICLE DRIVE CONCEPT
(WORKSTATIONS AND SPACECRANE NOT SHOWN)

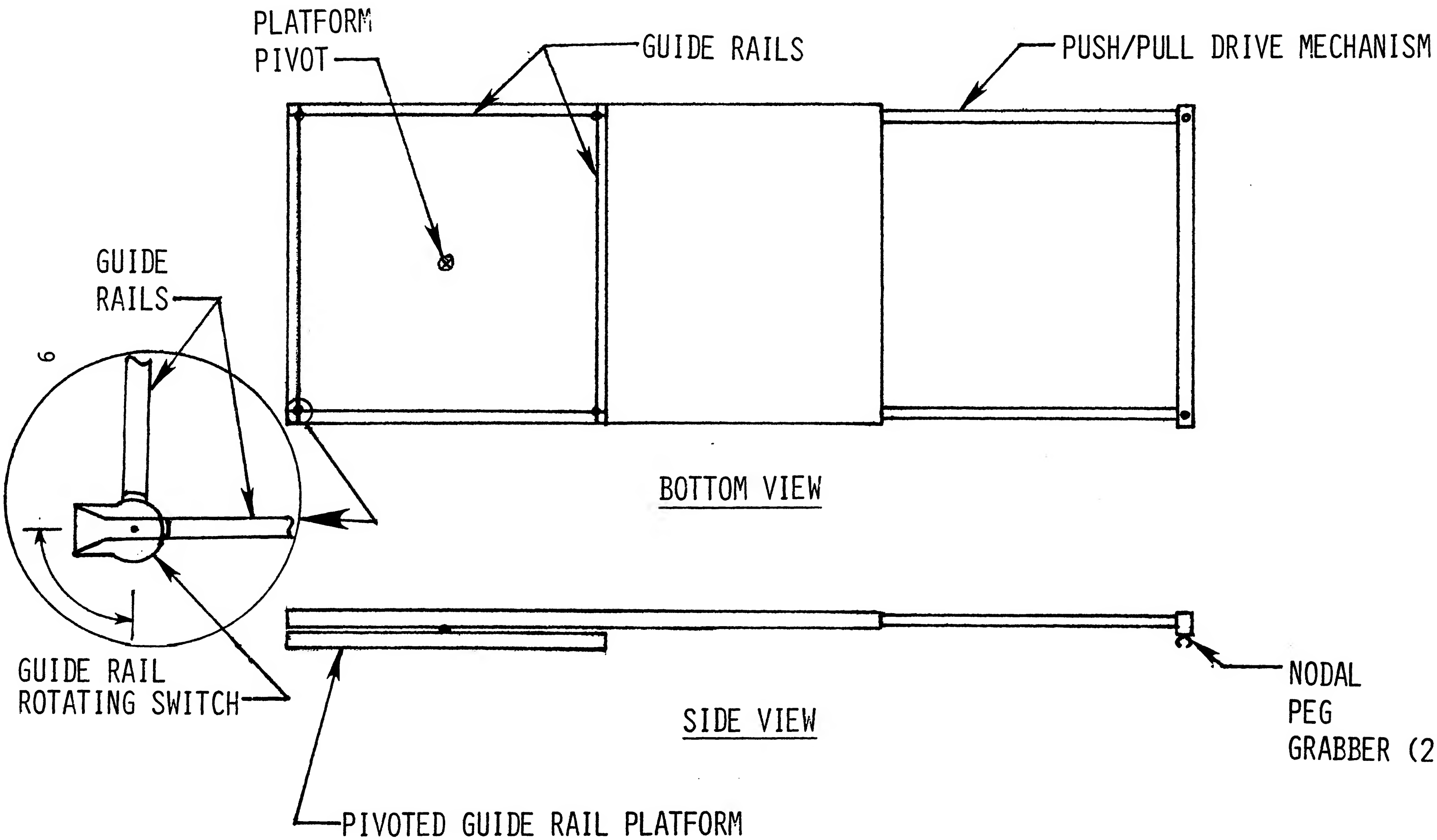


FIGURE 4

FIGURE 5

ASSEMBLY AND TRANSPORT VEHICLE TRANSLATION

Translation of the ATV is accomplished by operation of the push/pull drive mechanism to move the platform longitudinally in an "inch-worm" fashion. This sequence of events is illustrated in the upper half of figure 5. Transverse translation involves use of the pivoted guide rail platform as well as the push/pull drive mechanism, and is illustrated in the lower half of figure 5. Sketch (A) shows the ATV pivoting 90° from the direction of travel to construct an adjacent truss cell. Sketch (B) shows a 180° rotation to construct a auxiliary cell which is required to move to the next row. Sketch (C) shows that the auxiliary cell is used to push from, sliding the pivot platform onto the 1st cell constructed. Sketch (D) shows a 90° rotation into a position parallel, but on an adjacent row, to the original. Sketches (E) and (F) show longitudinal motion and construction of added cells to complete a platform. This operation is only needed once to start a platform. The auxiliary cell can either be incorporated into a row of the platform or disassembled, as desired.

ASSEMBLY AND TRANSPORT VEHICLE TRANSLATION

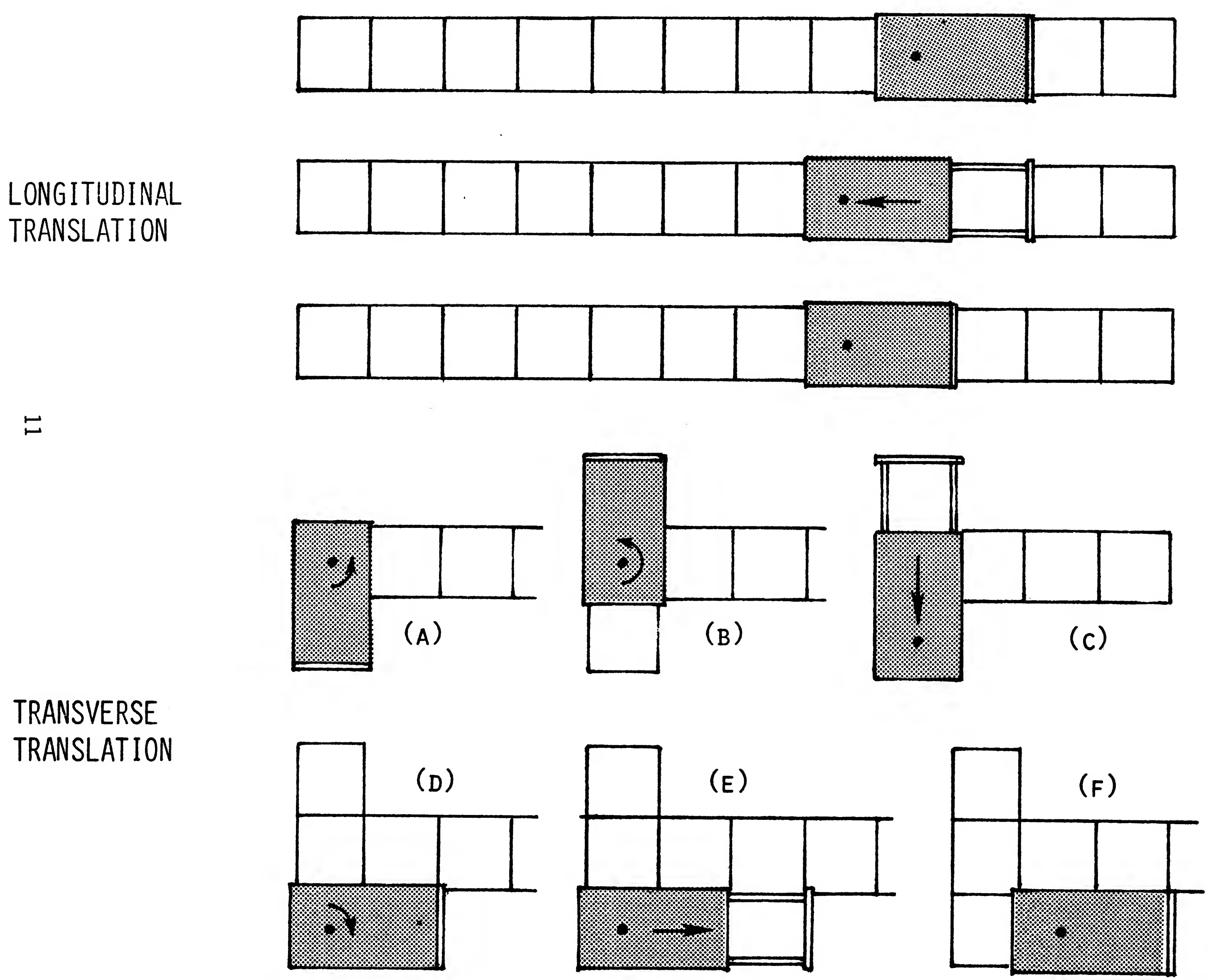


FIGURE 5

FIGURE 6

"PEG BOARD" PLATFORM CONFIGURATION

Using the ATV in the manner previously described, spacecraft such as the Space Station "Peg Board" Platform Configuration shown in figure 6 may be built. The central platform shown consists of 498 struts and 128 nodal cluster joints. It serves as the structural connection between manned modules which are transported from Shuttle to the installation site and positioned with the ATV outfitted with a "spacecrane" manipulator. After installing the gimbal hardware and structure, the ATV translates across the gimbal and is used to construct the four longeron beam solar array support structure. The entire solar array support structure shown (minus gimbals) consists of 328 struts and 104 nodal clusters. As each two bay (28') beam segment is completed, solar array modules (blankets or folded panels) are attached and deployed.

Considering the structural truss configuration shown to be assembled using 2 inch diameter struts, all components required except gimbal rings, would occupy a volume of 5' x 5' x 20'. An initial estimate is that these components would have a mass of approximately 4500 lbm. Installation of power transmission and control hardware is accomplished along with the structural assembly process using the ATV. The ATV can also be used to transport payloads to the opposite side of the platform from the Shuttle location by translating over the gimbal onto a "solar wing." After the "wing" rotates through 180°, the ATV is translated back onto the platform.

"PEG BOARD" PLATFORM CONFIGURATION
(150 KW)

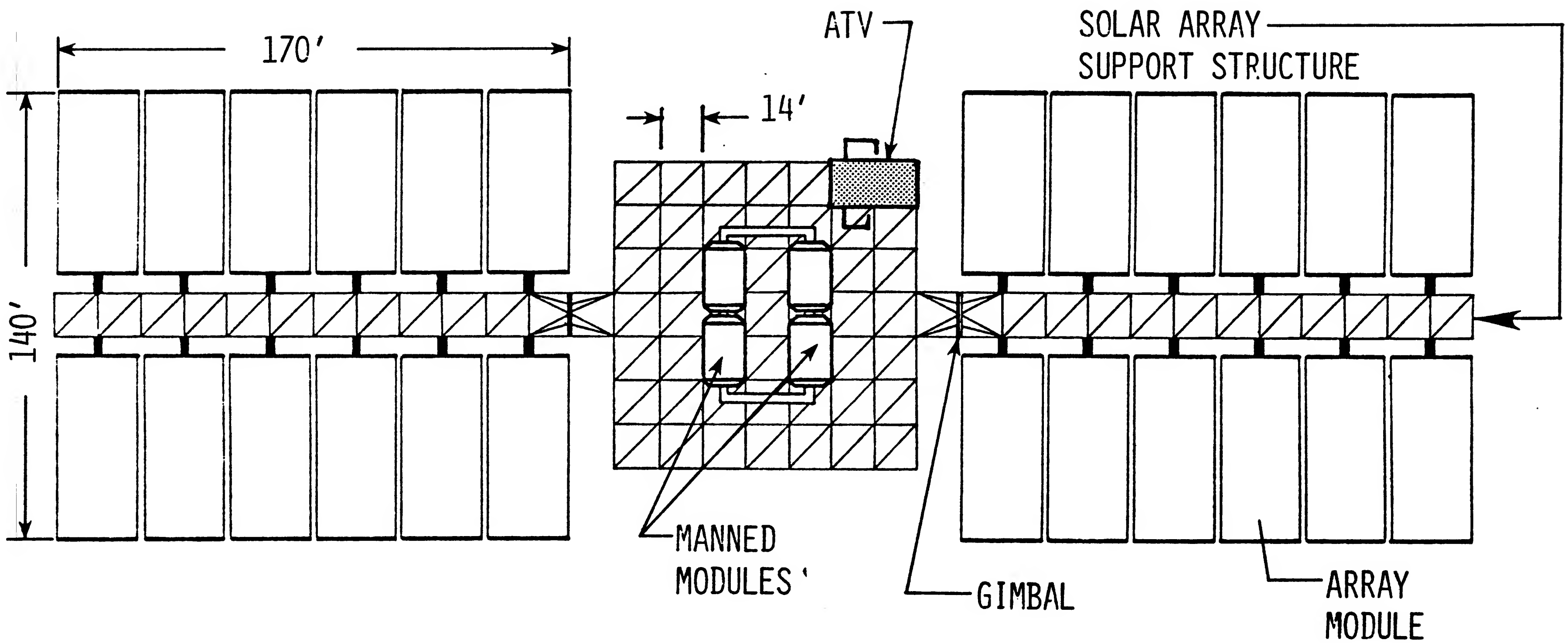


FIGURE 6

FIGURE 7

GRAVITY GRADIENT STABILIZED CONFIGURATION

An alternative space station configuration which has been studied is shown in figure 7. The space station essentially consists of a long beam, from which the solar array support structure is gimballed. Functional modules are grouped near one end of the long beam so that the spacecraft may be gravity gradient stabilized. Like the platform configuration of figure 6, this configuration can be constructed and maintained with the Assembly and Transport Vehicle.

GRAVITY GRADIENT STABILIZED CONFIGURATION

(150 KW)

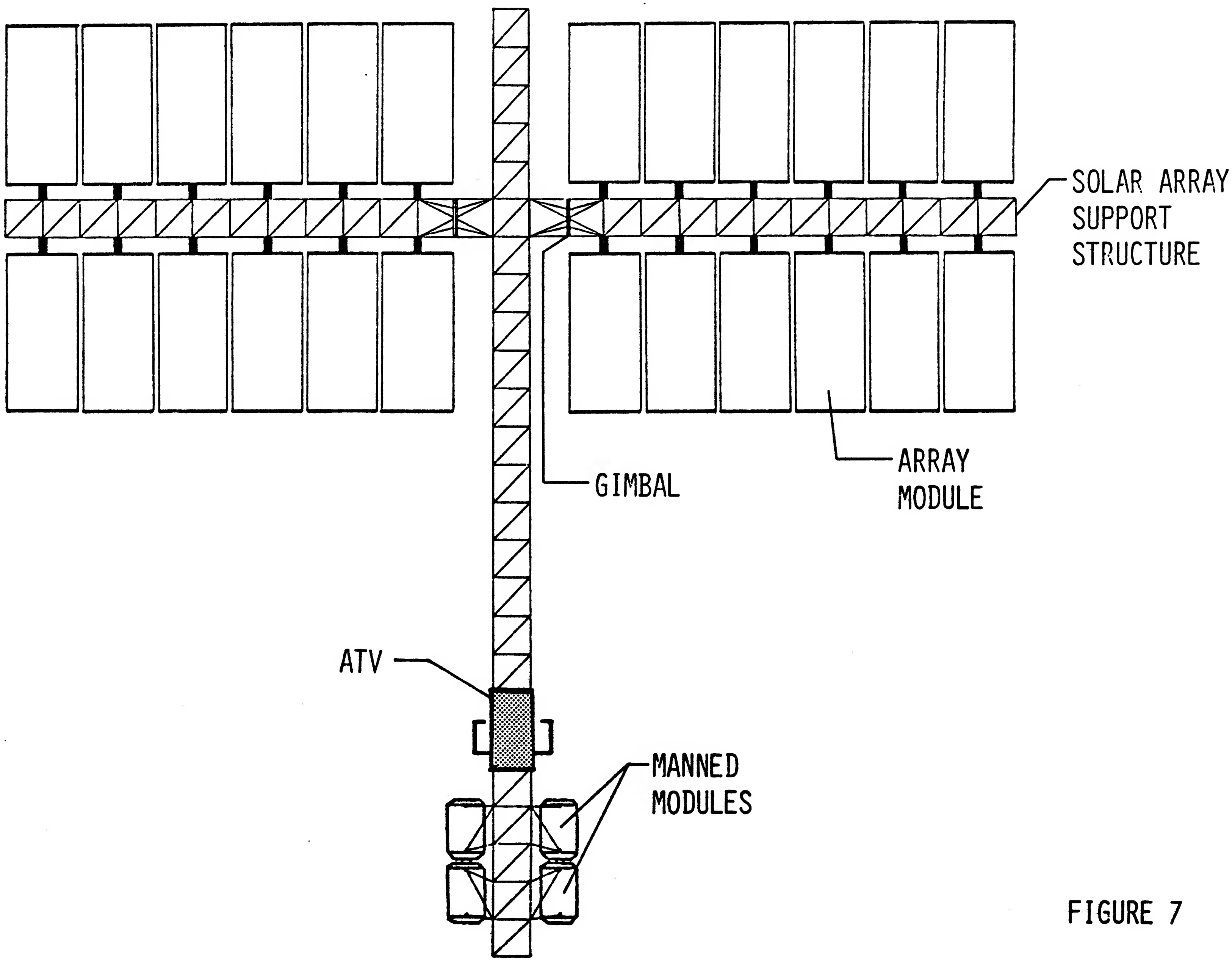


FIGURE 7

FIGURE 8

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(ARTIST SKETCH OF PROPOSED OBSERVATORY)

In addition to assembling a space station platform and solar arrays shown in the preceeding illustration, the ATV can be used to assemble other space structures such as large antennas and astronomical observatories. Several studies have been conducted to define the technical requirements for an orbiting submillimeter astronomical observatory (refs. 11 and 12). An artist sketch from reference 11 illustrating the proposed observatory is shown in figure 8. This proposed observatory would require a parabolic primary mirror with a diameter of up to 30m having diffraction limited optical quality. The mirror must be shaded from stray light and passively maintained at a constant temperature in the range of 150-200K. Primary mirrors with an f/D from 0.5 to 1.0 are of interest and to maintain the desired thermal conditions, the mirror must have a circumferential sunshade with a length approximately equal to the mirror diameter.

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(ARTIST SKETCH OF PROPOSED OBSERVATORY

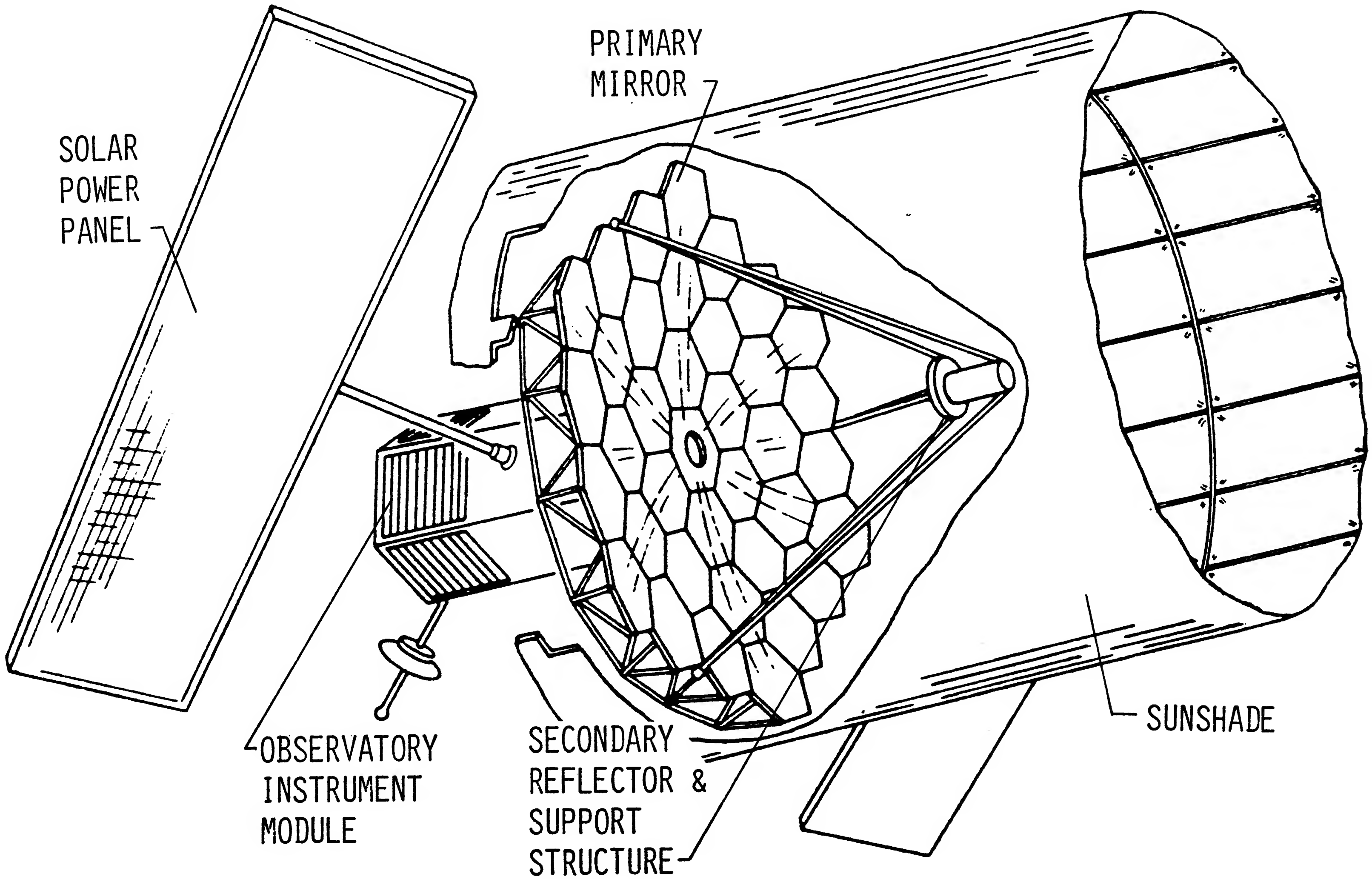


FIGURE 8

FIGURE 9

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY ASSEMBLY CONCEPT USING ATV

The construction scenarios developed in refs. 11 and 12 are built around the use of deployable modules or tetrahedral substructures on which hexagonal mirror facets are located using a special remote manipulator. An alternative to these approaches is to use the ATV concept to assemble the truss support structure and attach the mirror facets. The current figure and 4 subsequent figures are used to demonstrate an alternative scenario to those of refs. 11 and 12. The construction would be initiated by attaching a module containing the focal plane and various other observatory instruments to the space station truss platform using a "temporary" support structure. This structure would permit the instrument module to pivot about its centerline. The centerline is canted to the plane of the station platform approximately 7^{o} ($f/D = 1$, $D = 30m$). The proposed assembly sequence for the primary mirror is shown in the next figure.

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(ASSEMBLY CONCEPT USING ATV)

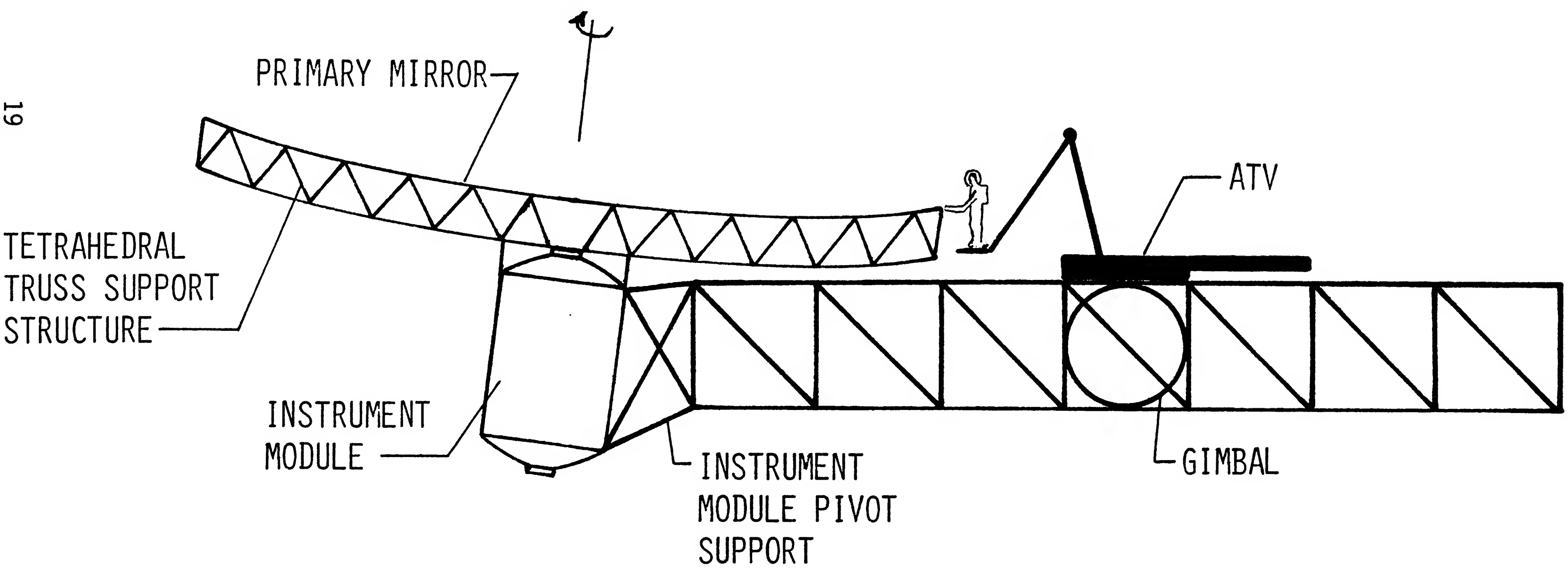


FIGURE 9

FIGURE 10

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
PRIMARY MIRROR ASSEMBLY

Construction of the primary mirror would be initiated by astronauts assembling rings of tetrahedral truss support structure with the interior rings attached to the instrument module. As sections of the support structure are completed, hexagonal mirror facets are moved from the ATV and secured at three attachment points. Control actuators would be installed and connected as each facet is secured. The instrument module pivots about the mirror axis thus permitting the astronauts to assemble the mirror with moderate motion of the workstations to which they are attached and only linear translation of the ATV. The canted axis of the instrument module permits the entire mirror to be assembled with changes in elevation of the astronauts of less than 1m. For this configuration, the size of the truss elements and the distance between parallel sides of the facets is considered to be about 2 meters. One or two rings could be assembled during each revolution of the module. The dark circle in the center of the mirror represents a hole which is required for the Cassegrainian system.

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(PRIMARY MIRROR ASSEMBLY)

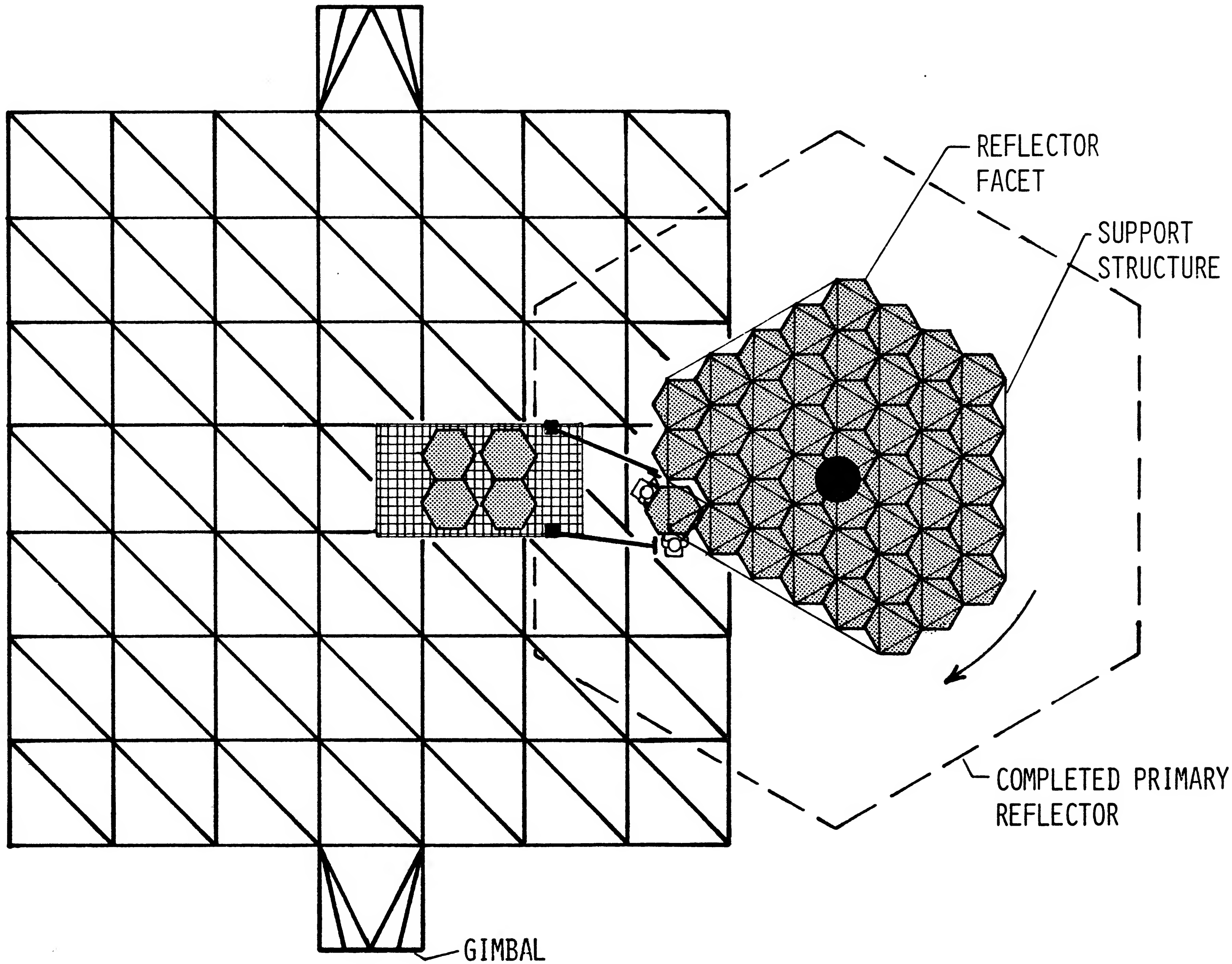


FIGURE 10

FIGURE 11

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
SUNSHADE ASSEMBLY

Upon completion of the primary mirror, which in the configuration shown, contains 140 facets and is 28m along a diameter to opposite corners, the sunshade would be assembled. The sunshade may consist of a number of tubular structural elments that are joined together using simple latch connectors (eg. see ref. 3). Between these members would be an overlay blanket of optically opaque material that has a high thermal resistance. Upon assembly of the shield for one side of the hexagons, the shield would be pivoted at the mirror-shield intersection and moved to the operating position using a manipulator arm (not shown) on the ATV. It should be noted that the length of the sunshade may require the truss platform to be extended by 1 to 2 bays. The modularity of the truss platform will easily permit this temporary extension which can be removed following completion of the observatory. The commonality of platform joints and members would permit the extension from new members or by reconfiguring the existing platform using joints and members which were otherwise not needed (eg. corner sections of the platform above or below the ATV position shown).

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(SUNSHADE ASSEMBLY)

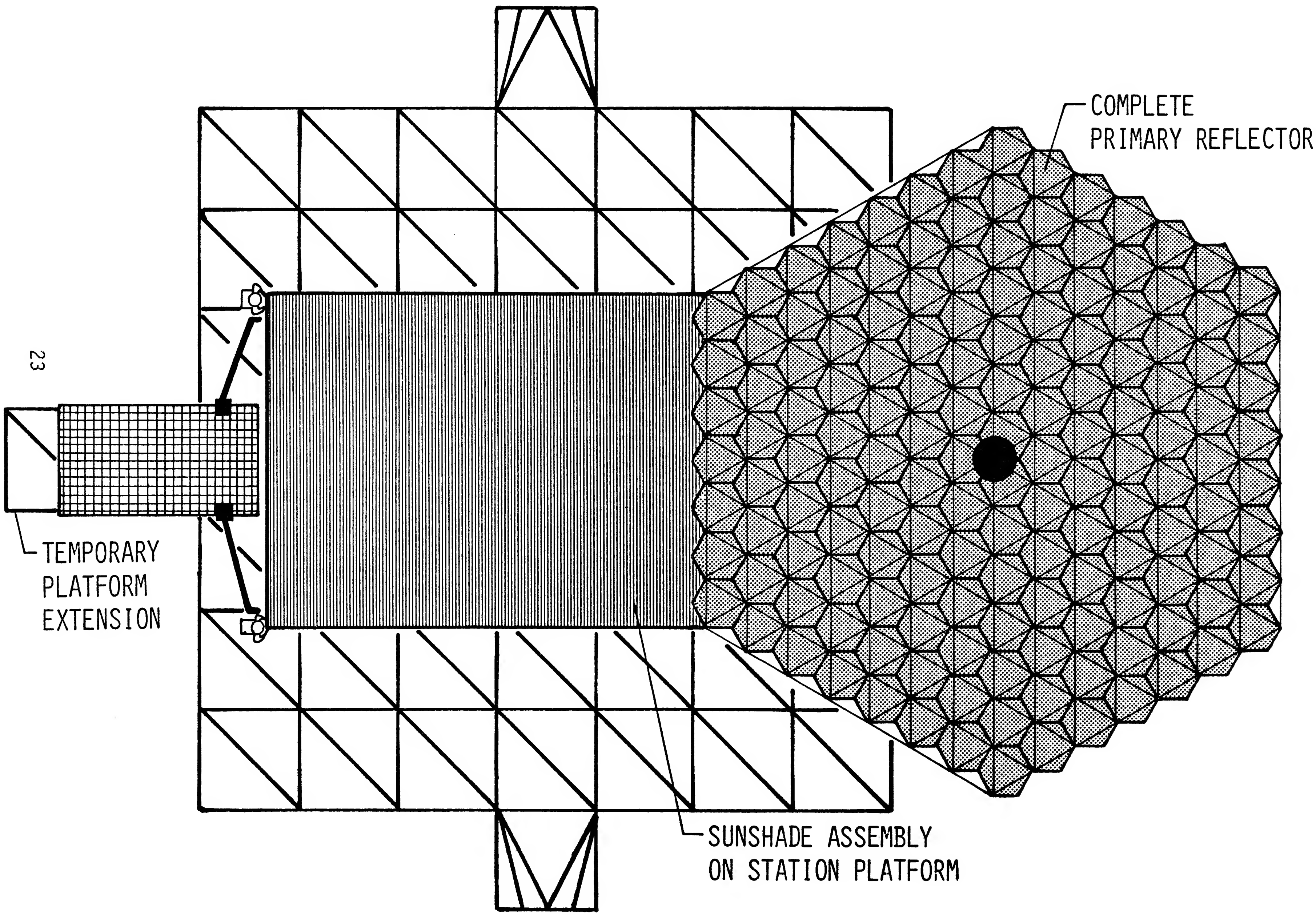


FIGURE 11

FIGURE 12

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
SECONDARY REFLECTOR SUPPORT STRUCTURE

Following assembly and positioning of the sunshades on two sides of the hexagon, the support structure for the secondary reflector can be assembled. This may require from 3 to 6 support columns which could be circular tubes connected together or an assembly of members in the form of a truss. All members would be assembled in the vicinity of the platform as shown on the figure with the secondary reflector positioned on the ATV or on a special platform support. Following assembly, one member can be raised and locked in position to form a tripod configuration. The tripod may then be moved into the final position by rotating the assembly about the two attachment points to the reflector support structure.

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(SECONDARY REFLECTOR SUPPORT STRUCTURE)

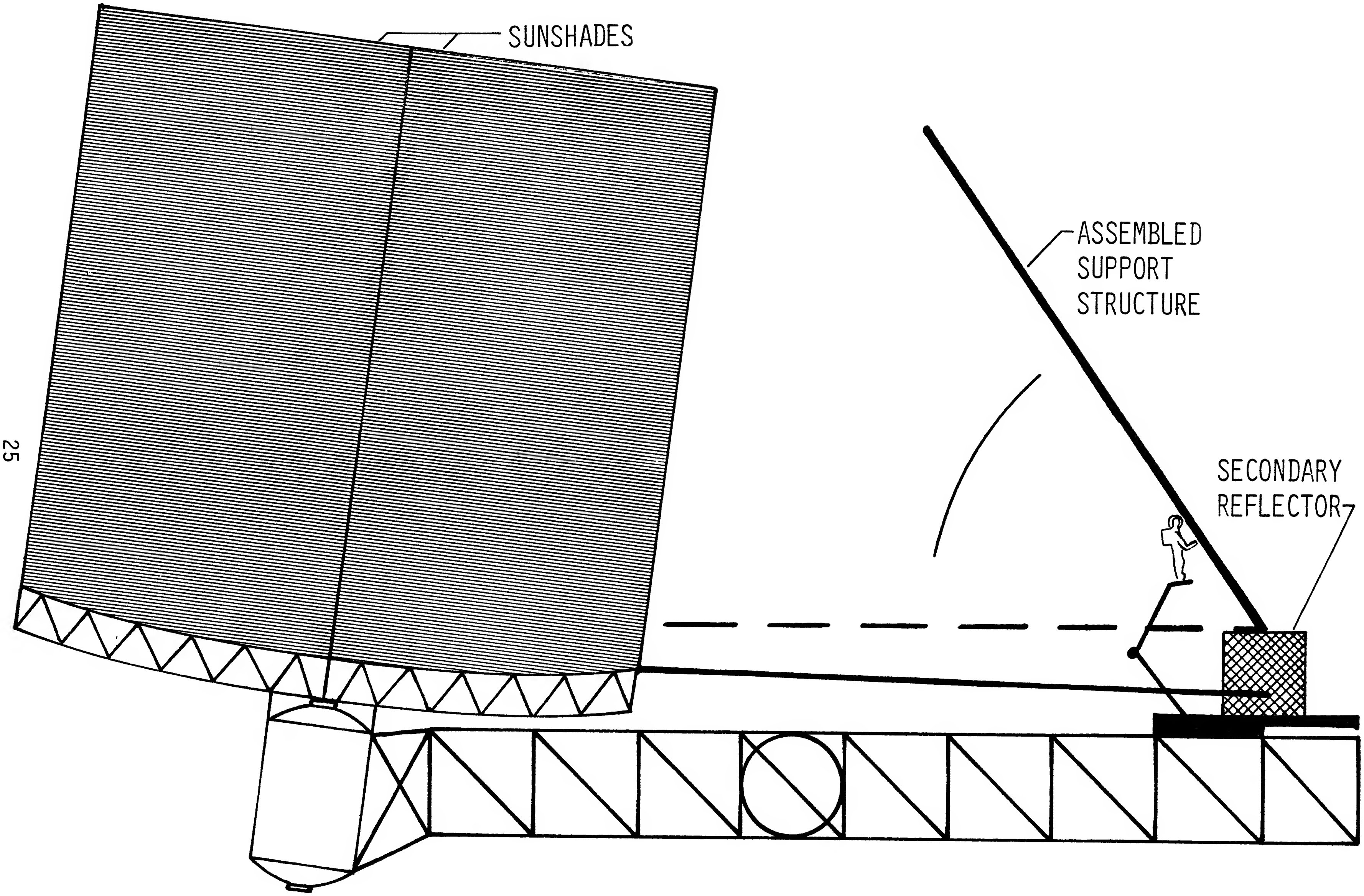


FIGURE 12

FIGURE 13

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
SECONDARY REFLECTOR IN PLACE

The secondary reflector and its support structure are shown in the figure in the operating position. The remaining 4 sunshade sides can then be assembled in order and moved into position. A final connection of the third tripod leg may be required during assembly of the sunshade on the 6th side which would complete the assembly process.

Construction of large, optically accurate, structures in space is a challenging assignment. While other construction scenarios have been proposed for the Submillimeter Astronomical Observatory, they generally require sophisticated deployment schemes which in many cases are unproven and will require considerable technology development. The construction technique proposed herein is within the current state of technology and could be readily implemented. It also demonstrates the versatility of an ATV-space platform combination and is only one of many potential applications.

LARGE SUBMILLIMETER ASTRONOMICAL OBSERVATORY
(SECONDARY REFLECTOR IN PLACE)

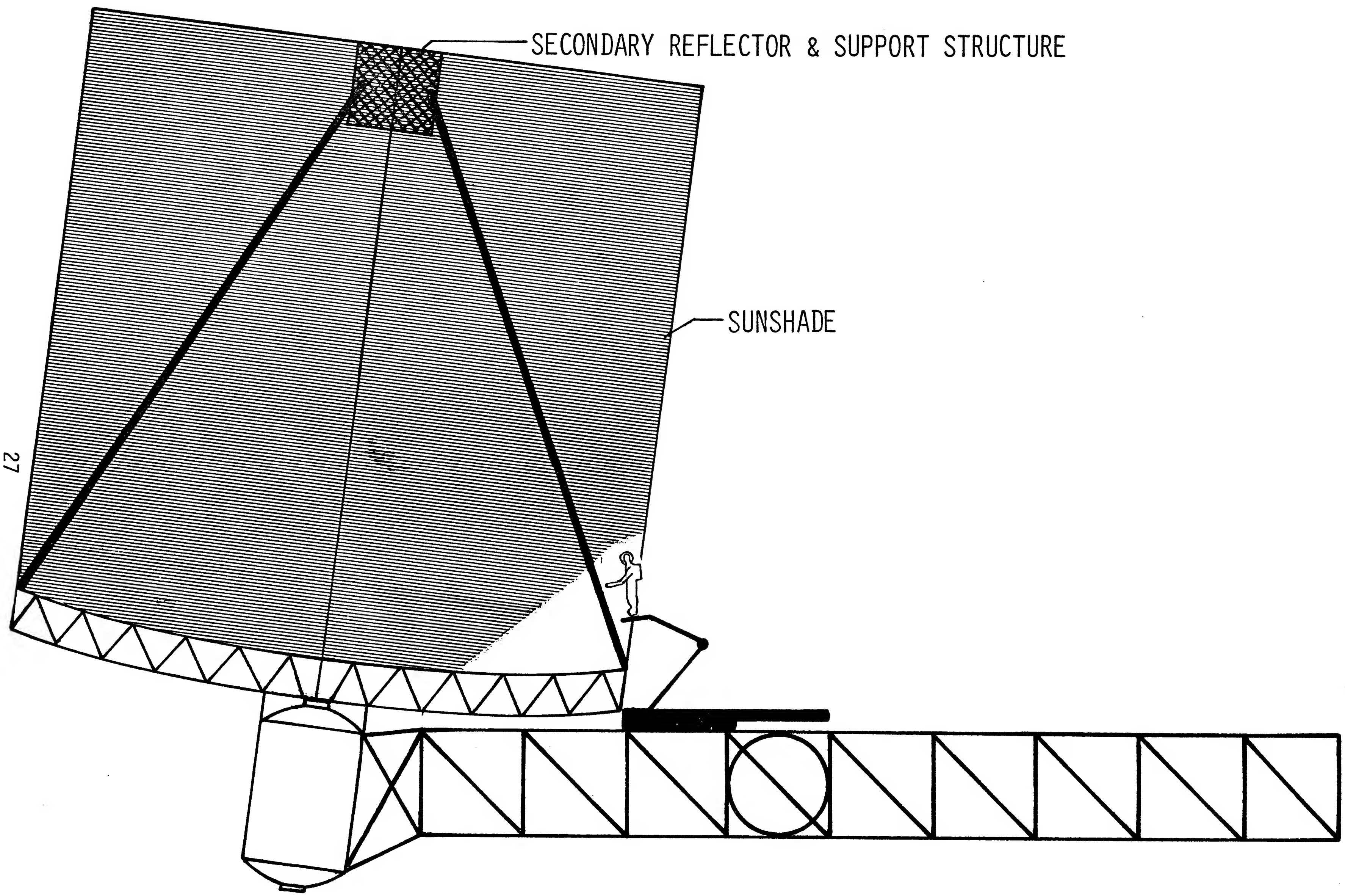


FIGURE 13

FIGURE 14

ALTERNATIVE "PEG BOARD" PLATFORM CONCEPT (150 KW)

The construction concept presented in this paper was initially conceived for constructing large (150 kw continuous power) solar arrays for space station. It later became apparent that the ATV required for this operation could be a highly versatile tool capable of performing tasks related to constructing and maintaining the space station, as well as constructing large structures for other missions. In figure 14, a few alternative features for space station are shown. At the bottom of figure 14, a large antenna is shown being erected by the ATV. This is a slight variation to the antenna shown being constructed in figure 9 in that a special construction beam has to be erected by the ATV to move the construction operation away from the station core thus permitting a much larger antenna to be constructed. At the top of figure 14, a beam is shown having been erected by the ATV to support thermal radiators away from the station and power arrays. Also shown at the top of figure 14 is a docking port for Shuttle which could be accessed by the ATV for moving supplies or other elements about the space station as needed. Due to the complexity of transferring power and waste heat across the gimbal, it may be desirable to place modules requiring large amounts of power on the power array itself (see figure 14). Such a possibility is indicated on the right hand array wing of the station where two modules are shown attached perpendicular to the array support beam.

The use of an erectable approach along with the ATV permits any number of such station alternatives to be readily employed either initially or later as user defined operational needs arise. In summary, such an erectable approach permits the station to be built and readily modified in a systematic fashion to meet initial, as well as future requirements.

ALTERNATIVE "PEG BOARD" PLATFORM CONCEPT (150 KW)

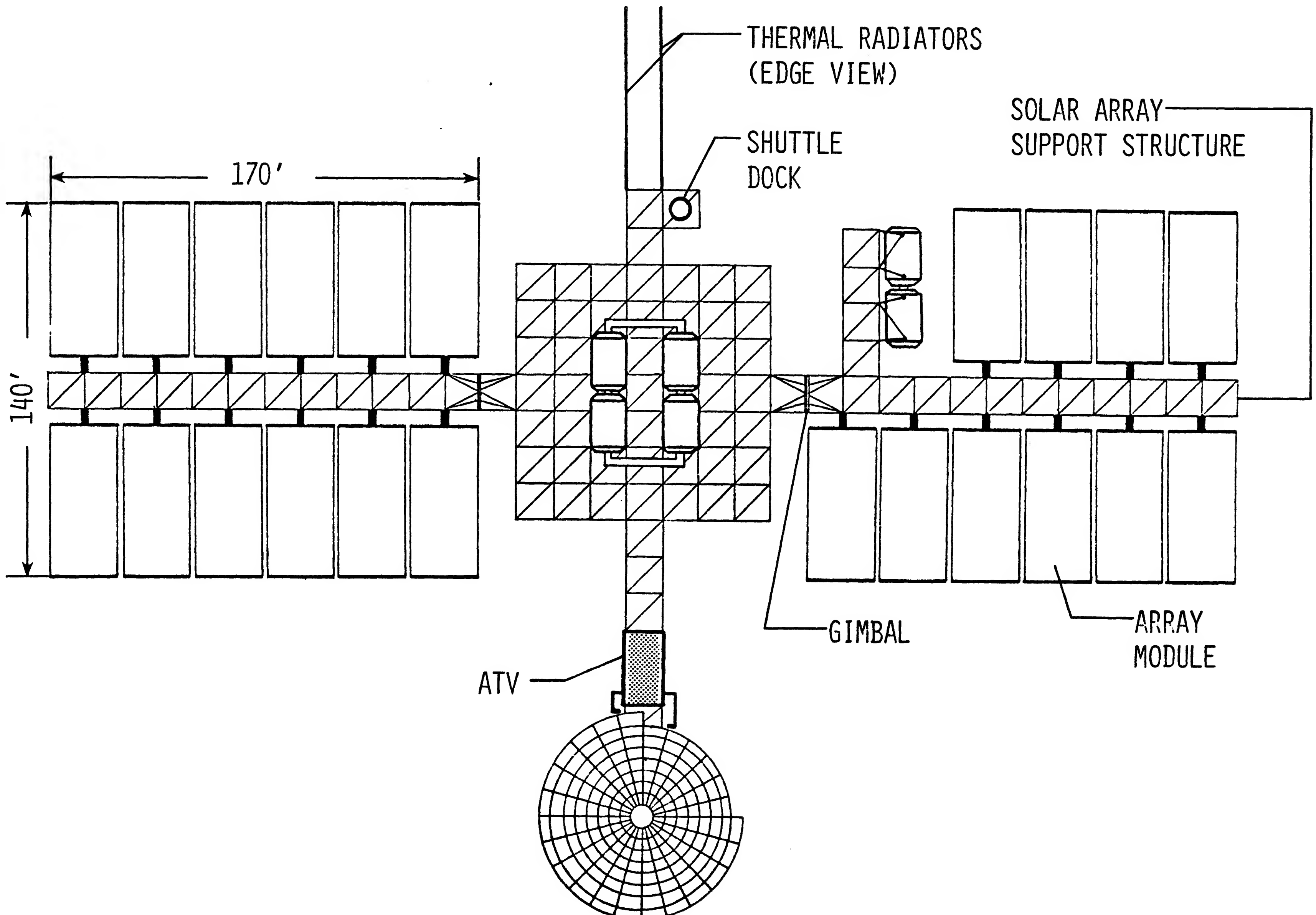


FIGURE 14

ERECTABLE APPROACH TO SPACE STATION CONSTRUCTION
SUMMARY

- o PROVIDES CAPABILITY FOR CONSTRUCTING "STIFF" SPACE STATION.
- o IRREGULAR ORTHOGONAL TETRAHEDRAL TRUSS HAS
  - — APPROXIMATELY 800 STRUTS FOR 150 KW VERSION
  - — 2 STRUT LENGTHS REQUIRED
  - — 1 JOINT DESIGN REQUIRED

  PACKAGE SIZE (5′ x 5′ x 20′)
  TOTAL WEIGHT ~ 4500 LBS
- o GREATLY ENHANCE MISSION FLEXIBILITY AND VERSATILITY.
- o PERMITS STATION MAINTENANCE INCLUDING SINGLE MODULE REMOVAL AND/OR ADDITION.
- o PROVIDES CONTROLLED TRANSPORT OF ALL PAYLOADS OVER ENTIRE SPACE STATION.
- o SHUTTLE "FREE FLYING" ACTIVITIES NOT REQUIRED.
- o EXTENDED REACH SHUTTLE RMS NOT REQUIRED.
- o PROVIDES CAPABILITY FOR CONSTRUCTING OTHER LARGE SPACECRAFT SUCH AS ANTENNAS OR POLAR PLATFORM.

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15. Supplementary Notes

16. Abstract

A design concept for the construction of a permanent manned space station is developed and discussed. The main considerations examined in developing the design concept are (1) the support structure of the station be stiff enough to preclude the need for an elaborate on-orbit system to control structural response, (2) the station support structure and solar power system be compatible with existing technology and, (3) the station be capable of growing in a systematic modular fashion. The concept is developed around the assembly of truss platforms by pressure-suited astronauts operating in extravehicular activity (EVA), assisted by a machine (Assembly and Transport Vehicle, ATV) to position the astronauts at joint locations where they latch truss members in place. The ATV is a mobile platform that is attached to and moves on the station support structure using pegs attached to each truss joint. The report describes the operation of the ATV and develops a number of conceptual configurations for potential space stations. The report also shows how the ATV could be used to assist in the assembly of other large space structures which would otherwise be very difficult to deploy or assemble in space.

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